Ship Auxiliary Engine Proposal
Q&A for May 2005 Workshop

1. Question: How much does fuel sulfur increase the emissions of diesel particulate matter?

There are varying estimates of the effect of fuel sulfur on diesel PM. The estimates vary with the estimated percent conversion of fuel sulfur to sulfate. The percent conversion estimates range from two to five percent. USEPA has estimated a 2% conversion rate, while other testing indicates higher conversion rates in the 4-5% range. The table below shows the expected increases in sulfur derived PM (as sulfate) using two and four percent conversion rates. However, note that sulfate is only one component of the total PM emissions. Other components of the PM include carbon (soot), ash, and soluble organic hydrocarbons.

Estimated Sulfate PM by Fuel Sulfur Content and
Different Sulfate Conversion Rates

Fuel Sulfur (% by weight)	Sulfate (g/kw-hr) @ 2% conversion	Sulfate (g/kw-hr) @ 4% conversion
3	0.91	1.82
2.7	0.82	1.64
2.5	0.76	1.52
2	0.61	1.22
1.5	0.46	0.92
1	0.30	0.60
0.5	0.15	0.30
0.4	0.12	0.24
0.3	0.09	0.18
0.2	0.06	0.12
0.1	0.03	0.06
0.05	0.015	0.03

Note: These estimates are based on the following equation recommended by USEPA staff using a 2% or 4% sulfur to sulfate conversion per USEPA and brake specific fuel consumption of 217 g/kW-hr:

Sulfate diesel PM (in g sulfate/kW-hr) = BSFC x % sulfur in fuel x (MW sulfate/MW sulfur) x sulfur to sulfate conversion %.

Where: BSFC = brake specific fuel consumption, MW ratio (sulfate to sulfur) = 7 (where “sulfate” is H_2SO_4 plus 7 H_2Os)

2. **Can the use of marine diesel oil (MDO) be considered in addition to marine gas oil (MGO) as long as it meets the same sulfur content limit?**

We are currently proposing to allow the use of MDO (or "DMB") in our proposal for ship auxiliary engines. MDO is essentially MGO that has a limited amount of contamination from storage or transfer in tanks or lines that previously held residual fuels. As such, it contains a small amount of residual fuel, which would be expected to increase its sulfur content and change some properties slightly. A report prepared for USEPA estimates that typical MDO is over 99% distillate while MGO is 100% distillate. It also reports higher sulfur and viscosity for MDO as follows:

Actual Properties of MGO and MDO (averages)

Property	MGO	MDO
Sulfur (weight percent)	0.36	0.91
Kinematic viscosity (cSt@40C)	3.2	4.5
Ash	0.0	0.0

Source: 1997 DNV Petroleum Services data from 27 US ports

Based on the estimate that MDO is over 99% distillate fuel, it appears that MDO with an equivalent sulfur content to MGO would result in similar PM emissions. It is also likely that MDO meeting a relatively low sulfur content (such as 0.2%) would have a lower than average level of contamination with residual fuel.

3. **Why have the provisions for "frequent visitors" presented at the last workshop been deleted from the proposal for ship auxiliary engines?**

Some commenters at the last workshop suggested that the provisions for vessels which make frequent port calls should be considered separately. We agree and have removed these provisions. Developing a proposal for frequent visitors will be more complex than the cleaner fuel provisions. In order to allow for adequate time to develop this proposal, and prevent the risk of delaying the cleaner fuel provisions, we have decided to develop a strategy to address frequent visitors next year.

4. **What is the estimated cost and cost-effectiveness of the proposed fuel requirements?**

The cost of the proposed regulation includes the higher cost of marine gas oil (MGO) and the cost of potential vessel modifications to accommodate the storage and use of MGO in vessels not currently equipped for it. With respect to the cost of the fuel, MGO is currently about double of the cost of residual oil. This would result in roughly an extra $5,000 for a typical container ship visit to a California port with a 2 megawatt total auxiliary engine load and 60 hours of operation within California Coastal Waters. For perspective, the total cost of fuel for a round trip voyage by a typical container ship from Asia to the Port of Los Angeles, would be roughly one million dollars depending on the number of ports visited. The cost effectiveness of the proposal would be about $30,000 per ton of PM reduced, which is similar to the cost-effectiveness of the ARB's recently adopted stationary diesel engine Air Toxic Control Measure. The cost-effectiveness for typical vessels that make five annual port visits and require modifications of $100,000 would be about $44,000/ton PM emissions (or 4,600 per ton of NOx/SOx/PM combined). The estimated cost and cost-effectiveness calculations are attached.

5. **How will diesel electric vessels such as cruise ships and some tankers be covered by the proposal?**

As currently proposed, the regulation would apply to the generator set engines used on diesel-electric vessels. Most vessels have one large main engine used primarily for propulsion, and one or more auxiliary engines used for on-board electrical power. This proposal focuses on the auxiliary engines because they are smaller, medium speed four-stroke engines more readily amenable to the use of lower sulfur distillate fuels. Diesel-electric vessels use large diesel generators to generate electrical power for both propulsion and onboard electrical needs. We have included these engines in the proposal to use distillate fuel because they are similar to the auxiliary engines used on cargo vessels in that they are generally four-stroke, medium speed generator-set engines. However, we recognize that they are much larger and use more fuel since they provide power for propulsion as well as onboard power needs. For example, we estimate the *added* fuel cost for a typical cruise ship visiting the Port of Los Angeles or Long Beach from Ensenada would be $16,000 round trip, above a base cost of about $34,000.

However, the emissions reductions would also be greater, so the cost-effectiveness would remain unchanged and still be attractive.

The operators of diesel electric vessels have also raised concerns regarding the safety of switching fuels at sea in engines used for propulsion, and the fact that these vessels represent a minority of the vessels operating in California, yet are impacted more heavily than other vessels. ARB staff is continuing to investigate these issues to determine the best way to control emissions from diesel electric vessels.

6. What are the results of the Oceangoing Ship Survey?

In January 2005, ARB sent out a survey to 158 ship operators and agents. The mail list was compiled based on lists provided by the California State Lands Commission, trade association membership lists, and port handbooks. The survey requested information about oceangoing vessels that visited California ports in 2004. Specifically, information was requested about the vessels, engines, fuels used, and port visits. The information will be very important to the development of the proposed ship auxiliary engine rule, an update of the emissions inventory for oceangoing vessels, and the ARB's feasibility study of shore-side power ("cold ironing"). As of this writing, about 40 companies have responded to the survey. These companies operated 327 vessels in California in 2004. According to data from the California State Lands Commission, there were about 1900 unique ships that visited California ports in 2004. Therefore, we received information on about 17% of the vessels that visited California ports. Based on the respondents to date, we have a relatively good sample of container vessels, auto carriers and cruise ships, with a relatively poor response from bulk carriers, tankers, and general cargo. However, we are still receiving some late submittals and strongly encourage companies that have not yet completed the survey to do so as soon as possible. Based on the data received to date, ARB staff has prepared a summary of the results. Some key data for the development of the auxiliary engine proposal is as follows:

? The Auxiliary engines reported in the survey are all four-stroke
? The top five auxiliary engine manufacturers, representing nearly 90% of the engines in the survey, are MAN B&W, Daihatsu, Wartsila/Sulzer, Yanmar, and MAK
? Seventy-eight percent of the surveyed auxiliary engines run on residual fuel, with the remaining engines operating on distillate diesel

- ? The average sulfur content of residual and distillate fuels is 2.5% and 0.5% respectively
- ? Cargo vessels have an average of about 3 auxiliary engines, while cruise ships have an average of nearly 5
- ? The average auxiliary engine loads for vessels reported was as follows:

	Total Auxiliary Engine Power (kW)		
Vessel Type	Hotelling	Maneuvering	Transiting
Auto Carrier	600	1,300	600
Container/Reefer	1,600	3,400	4,000
Passenger/Cruise	7,400	13,400	33,800
Tanker	500	650	450
Other	1,450	1,700	4,200

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Cost Increase for a Cruise Ship to the Use of Distillate Fuel on a Round trip visit to POLA/LB from Ensenada

I. Assumptions:

Fuel change from bunker (IFO 380) to marine gas oil (MGO)
Fuel Costs based on Bunkerworld 4/19/05 Singapore prices: $247/MT bunker & $469/MT for MGO
Total engine power of 30 MW for transiting, 13 MW maneuvering, and 7 MW hotelling
Ship port visit is 8 hours hotelling, 10 hours transiting (using 100 nm LA to Mexico and 20 knots x2 for round trip), and 2 hours maneuvering
Specific fuel consumption: 213 g fuel/k/W-hr for IFO 380 and 203 for MGO (ENTEC Report, Table 2.8)

II. Calculations:

Power

(8 hrs. hotelling x 7,000 kW) + (10 hrs. transiting x 30,000 kW) + (2 hrs. maneuvering x 13,000 kW) = 382,000 kW-hr.

Cost
Bunker: 382,000 kW-hr. x 213 g fuel/kW-hr. x lb/454 g x Ton/2,000 lbs x tonne/1.1 ton x $247/tonne = $20,121
MGO: 382,000 kW-hr. x 203 g fuel/kW-hr. x lb/454 g x Ton/2,000 lbs x tonne/1.1 ton x $469/tonne = $36,413

Cost Increase: ~**$16,300**

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Cost Increase and Cost Effectiveness Related to the Use of Distillate Fuel by Ships at Dockside and in California Coastal Waters

I. Assumptions:

Fuel change from bunker (IFO 380) to marine gas oil (MGO)
Fuel Costs based on Bunkerworld 4/19/05 Singapore prices: 247/MT bunker & 469/MT for MGO
Auxiliary engine load of 2MW for all auxiliary generators during hotelling, cruising, and maneuvering
Auxiliary generators are medium speed diesel engines
Ship port visit is 50 hours hotelling, 8 hours transiting, and 2 hours maneuvering (60 total)
Emission factors as follows:

- 14.7 g NOx/kW-hr with residual (Entec 2002)
- 13.9 g NOx/kW-hr with MGO (Entec 2002)
- 1.7 g PM/kW-hr with 2.7% sulfur residual (EPA/Environ 2002)
- 0.3 g PM.kW-hr with 0.25% sulfur MGO (Entec, 2002)
- 12.3 g SOx/kW-hr with 2.7% residual (Entec 2002)
- 1.1 g SOx/kW-hr with 0.25% MGO (Entec 2002)

Specific fuel consumption: 227 g fuel/k/W-hr for IFO 380 and 217 for MGO (ENTEC Table 2.10)
For vessel with fuel tank/pipe modifications necessary: $100k capital cost, 5 trips to a CA port annually, CRF of 0.1294 using 5% interest rate & 10 year project life, work done w/o impact to ship schedule

II. Calculations (w/o ship modifications):

<u>Emission Reductions (for a typical port visit)</u>
NOx: 2,000 kW x (14.7 – 13.9g)/kW-hr x 60 hrs x lb/454 g x Ton/2,000 lbs. = **0.106 Ton (211 lbs) NOx**
PM: 2,000 kW x (01.7 – 0.3g)/kW-hr x 60 hrs x lb/454 g x Ton/2,000 lbs. **= 0.185 Ton (370 lbs) PM**
SO_2: 2,000 kW x (12.3 – 1.1g)/kW-hr x 60 hrs x lb/454 g x Ton/2,000 lbs. **= 1.48 Ton (2960 lbs) SO_2**

<u>Cost</u>
Bunker: 2,000 kW x 227 g fuel/kW-hr x 60 hrs. x lb/454 g x Ton/2,000 lbs x tonne/1.1 ton x $247/tonne = $6,736
MGO: 2,000 kW x 217 g fuel/kW-hr x 60 hrs. x lb/454 g x Ton/2,000 lbs x tonne/1.1 ton x $469/tonne = $12,227

Cost Increase: **$5,491 (for a typical visit per assumptions above)**

<u>Cost Effectiveness</u>

NOx: $5,491/0.106 Ton = **$51,800/Ton**
PM: $5,491/0.185 Ton = **$29,700/Ton**
SOx: $5,491/1.48 Ton = **$3710/Ton**
Combined NOx/SOx/PM: $5,491/1.77 Ton = **$3,100/Ton**

II. Calculations (with ship modifications):

<u>Emission Reductions (same as above multiplied by 5 for five annual port visits</u>)
NOx: 0.106 Ton (211 lbs) NOx x 5 **= 0.53 Ton (1,055 lbs)**
PM: 0.185 Ton (370 lbs) PM x 5 **= 0.925 (1850 lbs)**
SO_2: 1.48 Ton (2960 lbs) SO_2 x 5 **= 7.4 (14,800 lbs)**

Total Cost

Fuel Increase: $5,491 x 5 = $27,455
Capital Cost: $100,000 x 0.1294 = $12, 943
Total Cost**: $40,398**

Cost Effectiveness

NOx: $40,398/0.53 Ton = **$76,200/Ton**
PM: $40,398/0.925 Ton = **$43,700/Ton**
SOx: $40,398/7.4 Ton = **$5,460/Ton**
Combined NOx/SOx/PM: **:** $40,398/8.86 Ton = **$4,560/Ton**

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Estimated Cruise Ship Residual Fuel Costs for Los Angeles to Ensenada Round Trip Voyage

I. Assumptions:

Fuel for main and auxiliary engines is residual - IFO 380
Fuel Cost based on Bunkerworld 4/19/05 Singapore price: $247/MT
Voyage is from Los Angeles to Ensenada – 160 nautical miles
Voyage speed at sea is 20 knots
Est. total engine loads: 7 MW hotelling, 13 MW maneuvering, and 30 MW transiting (ARB Ship Survey)
Ship hotelling time at each port is 8 hours
Ship maneuvering time is 2 hours at each port
Specific fuel consumption: 213 for auxiliary (ENTEC Table 2.8)

II. Calculations (w/o ship modifications):

<u>Fuel Consumed and Cost (for round trip visit</u>)

Engines at sea transiting:

Total hours: 160 nm x 2 (round trip)/20 nm per hour = 16 hours

Fuel: 16 hrs x 30,000 kw x 213 g fuel/ kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 102 tonne ($25,194 @ $247/MT)

Engines maneuvering:

2 hrs x 2 (round trip) x 13,000 kw x 213 g fuel/kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 11.1 tonne ($2,739 @ $247/MT)

Engines Hotelling:

Total hours: 8 hrs x 2 port stops x 7,000 kw x 213 g fuel/ kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 24 tonne ($5,900 @$247/MT)

Total:

137 tonne ($33,864 @ $247/MT)

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Estimated Container Ship Residual Fuel Cost for Simplified Transpacific Round Trip Voyage

I. Assumptions:

Fuel for main and auxiliary engines is residual - IFO 380
Fuel Cost based on Bunkerworld 4/19/05 Singapore price: $247/MT
Voyage is from Los Angeles to Hong Kong – 6363 nautical miles
Voyage speed at sea is 24 knots
Main engine is 40 MW (~ typical 4k TEU ship)
Main engine load at sea is 80%
Maneuvering load is 10%
Auxiliary generators total load is 2 MW at all times
Ship hotelling time at each port is 50 hours (100 for both port visits)
Ship maneuvering time is 2 hours at each port (4 hours for both port visits)
Specific fuel consumption: 195 g fuel/k/W-hr for main engine, 227 for auxiliary (ENTEC Report, Tables 2.8 & 2.10)

II. Calculations (w/o ship modifications):

<u>Fuel Consumed and Cost (for round trip visit)</u>

Main at sea transiting:

Total hours: 6363 nm x 2 (round trip)/24 nm per hour = 530 hours (22 days)
Fuel: 530 hrs x 40,000 kw x 80% load x 195 g fuel/kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 3,313 tonne ($818,311 @ $247/MT)

Main maneuvering:

2 hrs x 2 (round trip) x 40,000 kw x 10% load x 195 g fuel/kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 3 tonne ($741 @ $247/MT)

Auxiliary:

Total hours: 530 hours (transiting) + 4 hrs (maneuvering) +100 (hotelling) = 634 hours
634 hrs. x 2,000 kw x 213 g fuel/ kw-hr x lb/454 grams x ton/2,000 lbs x tonne/1.1 ton = 288 tonne ($71,136 @$247/MT)

Total:

3,600 tonne ($890,000 @ $247/MT)